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EFFECT OF SUPERPLASTICITY OF TITANIUM AND ITS ALLOYS AND THE USE OF THIS PHENOMENON IN WELDING IN THE SOLID STATE

M. Kh. Shorshorov, A. F. Tikhonov, N. I. Nadirashvili

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16. Abstract

The article discusses the results of a study of super-plasticity of titanium and some of its alloys, as well as the possibility of using titanium for intensifying the process by which a compound is formed in the solid state. It was assumed that intensification in welding depends on the speed of the movement of structural defects, intergrain slip, and diffusion.

The study was performed on the IMASH-5 S-65, a device for high temperature metallography with a chamber adapted for welding and dilatometric processes.

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EFFECT OF SUPERPLASTICITY OF TITANIUM AND ITS ALLOYS AND THE USE OF THIS PHENOMENON IN WELDING IN THE SOLID STATE

M. Kh. Shorshorov, A. F. Tikhonov, N. I. Nadirashvili

The author of [1] observed anomolously high indices of plasticity of technically pure titanium in tests performed in the phase transformation temperature interval. /140*

An important contribution to the study of superplasticity of titanium and its alloys was also made in [2-5]. The authors of [5], in particular, described the superplastic behavior of alloys of titanium, Ti-5% Al-2.5% Sn and Ti-6% Al-4% V in isothermal tests within the conversion interval; the effect was observed near the lower limit of the area of the β-phase. F-shaped curves characteristic of superplasticity were obtained, representing the elastic stiffness as a function of the deformation rate, and it was proposed that the index of sensitivity to the deformation rate m from the expression $\sigma=k\dot{\varepsilon}^{m}$ be used as a quantitative criterion of superplasticity. The maximum m = 0.8 and maximum elongation (>1000%) were observed at a comparatively low deformation rate (approximately $10^{-4}sec^{-1}$), and at the rate of $10^{-2}sec^{-1}$ m ≙ 0.3) the state of superplasticity disappeared. In this same paper, the dependence of the yield stress and the magnitude of m on temperature was established. Similarly, the activation energy ΔH was calculated, whose minimum value for the alloy Ti-5% Al-2.5% Sm was 50-65 kcal/mole.

The present paper presents the results of a study of superplasticity of titanium and some of its alloys, as well as the

*Numbers in the right-hand margin indicate pagination in the foreign text.

possibility of using it for intensification of the process of the formation of a compound in a solid state. It was assumed in this regard that the possibility of intensification of the welding process in the solid state is based on the acceleration of the movement of structural defects, the process of intergrain slip, diffusion, whose successful course in deformation or welding in superplastic modes requires the expenditure of less energy than under normal conditions.

The studies were performed on an improved device for /141
high temperature metallography, the IMASh-5 S-65 [1], whose working chamber was adapted for the performance of welding and dilatometric studies. The tests were performed in a vacuum of $5 \cdot 10^{-5}$ mm Hg using technically pure titanium and titanium alloys ZT5-1, OT4 and VT-14. The temperature intervals of the phase transitions were established by two methods: dilatometric analysis using the method and device of IMETDB** [7] as well as special experiments using the IMASh-5 S-65 device, employing the mechanotronic lamp of the 6MKh5S type. A comparison of the results obtained with the diagrams of anisothermal conversion showed good agreement.

As the basic parameter for the development of the effect of superplasticity, we selected a decrease in the magnitude of resistance to deformation. The quantitative criterion of the occurrence of the moment and the degree of development of superplasticity was also the parameter m. Experiments to determine /142
the dependence of the elastic stiffness σ of the materials upon the rate of deformation $\dot{\varepsilon}$ (Figure 1) were performed for isothermal deformation and using thermal cycling. The index of sensitivity to the rate of deformation m, whose high values indicate the existence of the effect of superplasticity, was determined as the tangent of the angle of inclination of curves σ and $\dot{\varepsilon}$ in logarithmic

*Institute of the Science of Machines.

**A.A. Baykov Institute of Metallurgy.

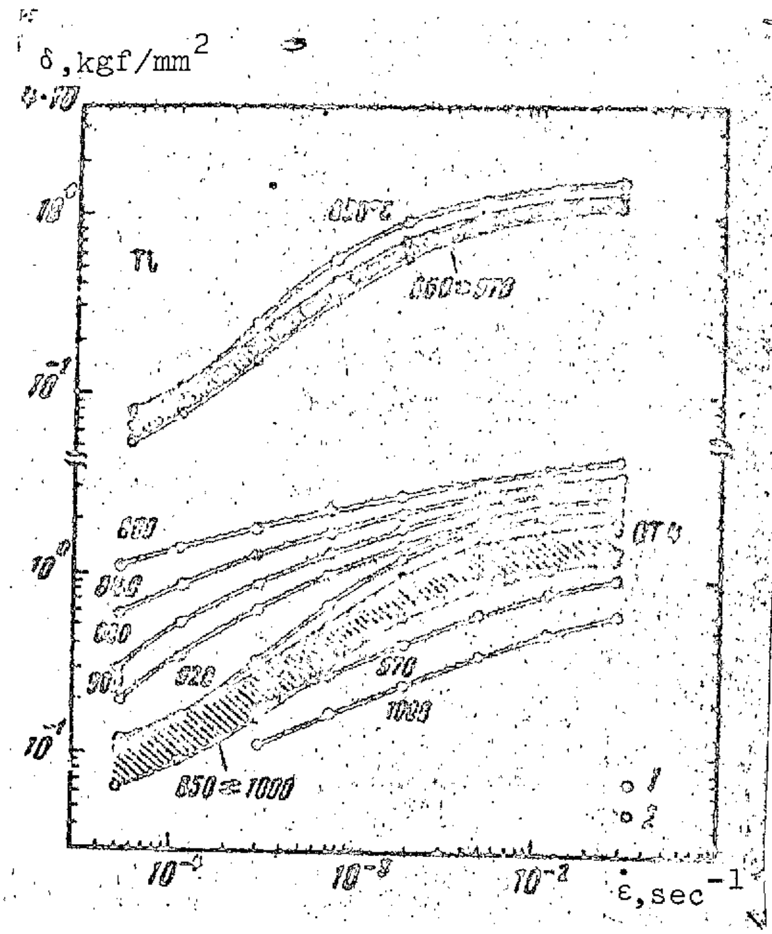

Fig. 1. Dependence of the resistance to deformation σ on the rate of deformation $\dot{\varepsilon}$ for titanium and the alloy OT4; 1--isothermal conditions of deformation; 2--using thermal cycling.

coordinates, and also by computation. The dependence of m upon $\dot{\varepsilon}$ (for titanium and alloy OT4) and upon temperature (for OT4) are shown in Figures 2 and 3.

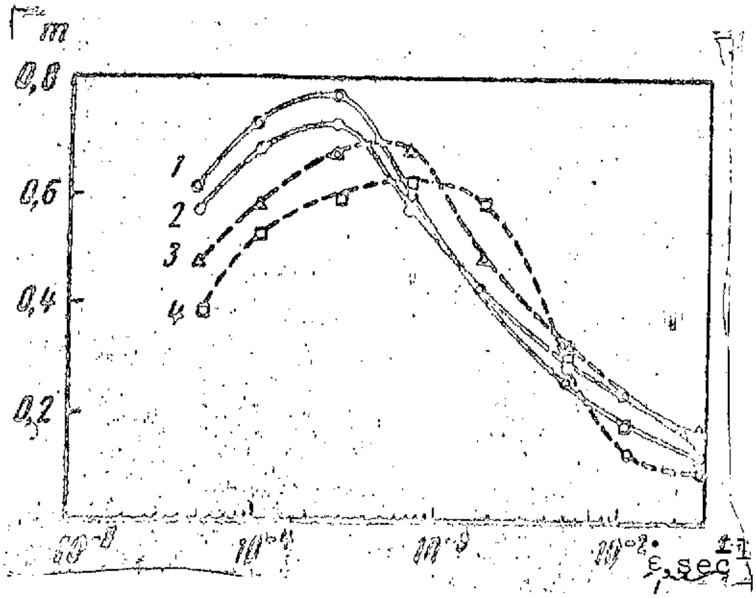

Fig. 2. Dependence of the [blurred] on the rate of deformation of titaniumand alloy OT4. 1--OT4, at 920°; Ti at 820°; 3--during deformation with thermocycling (860⇄ 920°, Titanium); 4--during deformation with thermocycling (830⇄ 1000°C, alloy OT4).

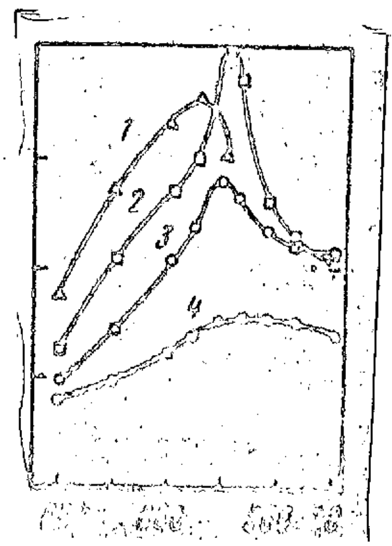

Fig. 3. Temperature dependence of the index m with $\dot{\varepsilon}$ = const for the alloy OT4. Rate of deformation, sec^{-1}: 1--$5 \cdot 10^{-5}$; 2--$3 \cdot 10^{-4}$; 3--10^{-3}; 4--$5 \cdot 10^{-3}$.

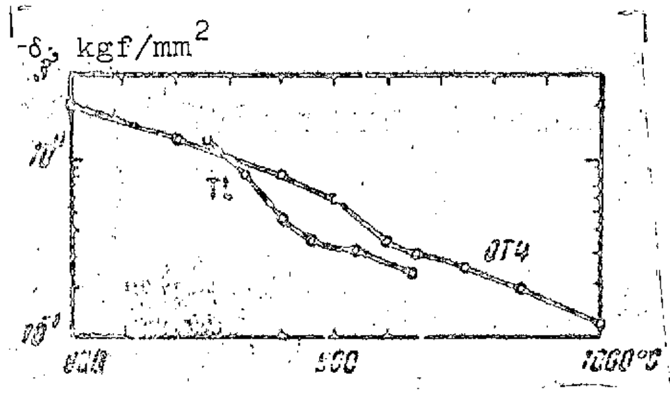

Figure 4. Dependence of the elastic stiffness upon temperature for titanium and alloy OT4 with a deformation rate $\dot{\varepsilon} = 3 \cdot 10^{-4} sec^{-1}$.

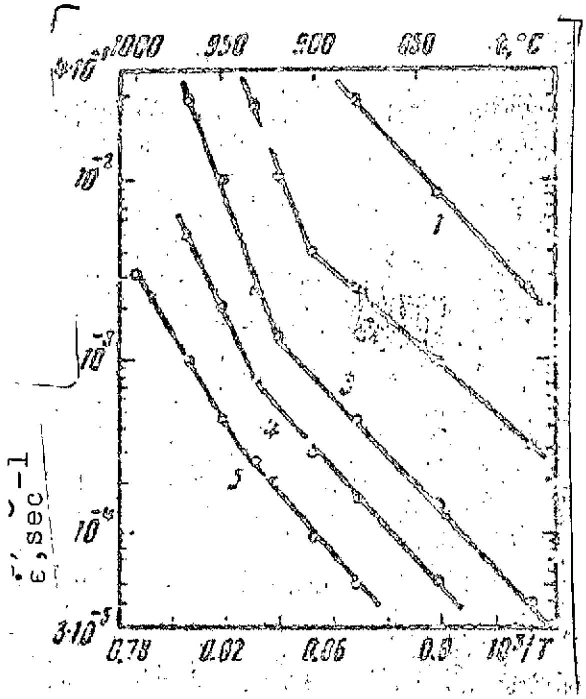

Figure 5. Rate of deformation versus absolute temperature for alloy OT4. Elastic stiffness σ , kgf/mm^2: 1--3.0; 2--2.0; 3--1.0; 4--0.6; 5--0.3.

Experiments were also performed to determine the optimum temperature of superplasticity within the conversion interval for a test rate obtained from previous experiments and corresponding to the maximum value of the parameter m. Results of these experiments for titanium and alloy OT4 are shown in Figure 4.

It is clear from Figure 1 that the value of σ under isothermal conditions is greater than the value of the elastic stiffness during thermal cycling, and the difference in the values of σ is proportional to the rate of deformation. A further decrease in $\dot{\varepsilon}$ creates a state of the material under test such that the nature of the change in temperature has no effect on the value of σ. One reason for this effect is clearly the exclusion of those specific characteristics which introduce deformation in thermal cycling (vacancy supersaturation of the aggregate, intensification of the field of internal stresses, promoting the development of superplasticity, decrease in the size of the nucleii of the new phase) at low deformation rates, resulting in a more effective pattern of relaxation processes.

A characteristic feature of the change in m is the fact that in comparison with isothermal conditions of deformation in tests using thermal cycling, the change in the sensitivity of the rate of deformation reaches its maximum value at high deformation rates (Figure 2). The difference is also indicated by the influence of the factors mentioned above.

It is clear from Figure 3 that a decrease in the testing rate of OT4 alloy not only decreases the maximum value of m but also shifts its maximum toward the lower temperatures, and at high rates ($5 \cdot 10^{-3}$ sec^{-1}) the maximum value of m is somewhat greater than 0.3

In Figure 4, using semilogarithmic coordinates, the dependence of the resistance of deformation on the test temperature is shown. In the case of Ti and alloy OT4, at a deformation rate corresponding to the maximum development of the superplasticity effect (for these materials $\dot{\varepsilon}_0$ is $3\cdot10^{-4}$ sec^{-1}) one can clearly see on the curve a deviation from the exponential law within the conversion interval.

In order to calculate the activation energy of the process, the data on OT4 from Figure 1 were replotted in coordinates for log $\dot{\varepsilon}$ and 1/T with σ [blurred] constant (Figure 5). From the expression $\dot{\varepsilon} = A\cdot\exp(-Q_\Sigma/RT)$ it follows that the activation energy Q_Σ may be determined as the tangent of the angle of inclination of the line log $\dot{\varepsilon}$ --1/T to the axis of the abscissa. With a minimum slope of Q_Σ = 60-80 kcal/mole, and with a maximum corresponding to the single-phase β-region, Q_Σ = 120-180 kcal/mole. The temperature corresponding to the discontinuity in the curves in Figure 5 is close to the transition temperature $(\alpha+\beta)\rightarrow\beta$. /143

On the basis of data in the literature, as well as the experimental results obtained in the present work, we can formulate the basic characteristics of the development of the effect of superplasticity in phase transformations that have a direct relationship to the problem under study in this work.

1. Within the temperature interval corresponding to the two-phase region there is an optimum temperature T_0 at which the effect of superplasticity is most completely evident. This is expressed ina noticeable decrease in the elastic stiffness, an increase in plasticity and the existence of extremal values of the coefficient m.

2. The optimum rates of deformation, at which the effect of superplasticity is observed, correspond approximately to 10^{-4} - 10^{-2} sec^{-1}.

3. The original grain size has an insignificant influence on the development of the effect of superplasticity in phase transformation.

4. The magnitude of the volume effect of transition $\Delta V/V$ is of great importance; as a rule, the effect of superplasticity using thermocirculation is more completely expressed as $\Delta V/V$ increases.

5. In a number of cases there has been a significant influence of the rate of temperature change $|\Delta T|/\dot{t}$ (both during heating and during cooling), consisting in an additional decrease in the active stresses with an increase $|\Delta T|/\dot{t}$.

6. Evidently the absolute magnitude and sign of the thermal effect of transition is of definite importance. The elimination or absorption of additional thermal energy in the phase transitions may influence the position of T_0 within the conversion interval, the degree of increase in elastic stiffness, and the magnitude of optimum deformation rate.

7. An evaluation of the activation energy of the deformation process Q_Σ in superplasticity modes and in the single phase β-region for alloy OT4 has shown that Q_Σ in the two-phase ($\alpha+\beta$)- region is about two times less than in the single phase β-region.

An examination of the experimental and theoretical data allows us to view the picture of the development of the effect of superplasticity in phase transformations in the following form.

At a given temperature within the transition interval and with a given rate of deformation $\dot{\varepsilon}_0$ conditions are created at which the polymorphic metal or alloy is characterized by an activated state of the atom similar to that which is observed in a transition to the solidus temperature. The position of T_0 within this interval is determined primarily by the area of the interphasal interface "matrix-nucleus of the new phase," the absolute magnitude and sign of the thermal effect of the transition, the heating or cooling rate, the level of internal stresses, arising during thermal cycling, as well as the externally applied stresses. The size of the interphase surfaces in this aggregate (in addition to the morphology of the system in question, depends significantly upon the number of atoms participating in the formation of the critical nucleus of the new phase.

In our opinion, the situation at the interface "matrix-new /144
phase" is very similar to that which is observed in melting at the boundary "solid phase--liquid phase"; the distinctive features of this situation are the following: (1) a very high diffusion mobility of the atoms in these layers; (2) facilitation of the development and movement of dislocations in the superficial layers of the crystals; (3) a decrease in the electron concentration in these layers. This problem was discussed in greater detail in [8], where, from the standpoint of diffusion theory, the kinetic theory of dislocations, the electron theory of metals and mechanics of deformation of solid media, the reasons for the development of the superplasticity effects were considered. In brief, a generalized model of the superplasticity has the following appearance:

$$\Phi(s, \sigma, T, \dot{\varepsilon}) \to \Delta C_f \to \left\{ \begin{array}{c} \Delta D \\ \Delta N(\tau_e, \dot{\varepsilon});\ \Delta v(\tau_e, T) \\ |\Delta e| \end{array} \right\} \to$$

→ highly plastic layer of width δ_{pg} ($\delta_{pg} \gg \delta$) → facilitation of the conditions of processes promoting superplasticity → $\Delta\varepsilon$

The function Φ in this diagram is a function of the structural factor s, the active stresses σ, temperature T, and the deformation rate $\dot{\varepsilon}$ and determines the degree of vacant supersaturation of the polycrystal ΔC_j. Supersaturation of the aggregate by vacancies and redistribution of the latter with local concentration near the grain boundary is a reason for the sharp increase in the level of diffusionability of the atoms ΔD, the increase in the density of mobile dislocation ΔN, and the rate of their movement ΔV in the boundary regions of the grains and promotes (due to the decrease in electron concentration in these points $|\Delta e|$) a decrease in the height of the Peierls barriers. Hence, at the phase separation boundary or the intergrain boundary a highly plastic layer with a width δ_{pg} develops (its width is much greater than the width of the grain boundary δ), characterizing the consequences of the extremely high capacity for softening by a very low elastic stiffness. The existence of such a highly plastic lamella at the interphase boundary produces a facilitation of the conditions for the occurence of processes that promote superplasticity (for example, intergrain slip) and as a consequence, an increase in the reserve of deformation capacity of the given aggregate. An increased tendency of superplastic aggregate toward relaxation of stresses is compensated for by their considerable tendency toward deformation and rapid hardening, which is expressed in a high experimentally observable uniform deformation of the samples during stretch.

Thermal cycling, which is used for additional "pumping" of vacancies into the superifical layers of crystallites, influences the aggregate more effectively as $\Delta V/V$ increases and promotes the development of a field of internal stresses whose realization is accomplished in the layers of the crystals near the surface. The increase in the rate of change in temperature during cycling near the transition may promote a decrease in the number of atoms participating in the formation of the nucleus, thereby increasing the area of the interphase surface responsible for the development of the superplasticity effect.

The combination of the concepts described above, touching on the analogy between the situations in phase transformation and during melting, served as a basis for using this defect in processes of joining of metals in the solid state. In the following we have presented some of the results we have obtained in this regard.

Experiments in the joining of titanium and its alloys in the solid state were performed under conditions corresponding to the optimum modes of superplasicity (see the table).

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OPTIMUM MODES OF SUPERPLASTICITY

Substance	Temperature °C		Rate ε, sec^{-1}		Stress, kgf/mm^2	
	isothermal	cyclic	isothermal	cyclic	isothermal	cyclic
Ti	890	860⇄920	10^{-4}	$5\cdot10^{-4}$–$2\cdot10^{-3}$	0.1–0.6	0.2–0.7
BT5-1	1010	940⇄1040	"	"	0.35–1.5	0.4–1.2
OT4	920	850⇄1000	"	"	0.15–0.8	0.3–0.8
BT14	900	780⇄930	"	"	0.3–1.6	0.4–1.[illegible]

An analysis of the experimental data on welding under optimal conditions of superplasticity has shown that the formation of physical contacts and volume interaction concludes after 2-3% deformation; a period of time on the order of 1 minute is spent in this and in microvolumes the process develops in several seconds. Tests of the impact strength of samples welded under these conditions fail to show any important difference between the base metal and the zone of the joint.

Hence the effect of superplasticity, observed in a number of metals and alloys, may be employed in the processes of joining metal materials in the solid state. It is necessary to have considerably less stress and time cycles which are used in industrial processes of the diffusion welding types. Other possible variations of the practical use of superplasticity are the intensification of the processes of forming, hardening during deformation in superplasticity modes, the use of this effect for the deformation of cast alloys, and also for artistic working of various metal materials. Some encouraging results on this level have already been obtained [9]. The use of the effect of superplasticity in production promises considerable economic savings.

REFERENCES

1. M. G. Lozinskiy. Stroyeniye i svoystva metallov i splavov pri vysokikh temperaturakh (The Structure and Properties of Metals and Alloys at High Temperatures). "Metallurgizdat", 1963.
2. R. Kot, V. Weiss. Syracuse University Research Institute Report (MET-E-1352-1066-FR), paper II, 1966.
3. O. Krause, V. Weiss. Syracuse University Research Institute Report (MET-E-1532-1066-FR), 1966.
4. Y. Oschida, V. Weiss. Syracuse University Research Institute Report (MET-E-1504-1067-FR), 1967.
5. D. Lee, W. A. Backofen. Trans. Metall. Soc. AIME, 1967, 239, 1034.
6. O. W. Greenwood, R. H. Johnson. Proc. Roy. Soc. 1965 (A), 283, 403.
7. M. Kh. Shorshorov. Metallovedeniye svarki stali i splavov titana. Izd-vo "Nauka", 1965.
8. A. S. Tikhonov, M. Kh. Shorshorov. Obobshchennaya model' sverkhplastichnosti metallov i dvukhfaznykh splavov (A Generalized Model of Super-Plasticity for Metals and Two-Phase Alloys). Moscow, VINITI, Dep. No. 3072-71, 1971.
9. A. S. Tikhonov. Deformability of Alloys of the Al-Si System. FKhOM, 1972, No. 2.